Correlation of Sequences and the Global Eustasy Paradigm: A Review of Current Data

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Summary

An increasingly detailed stratigraphic record and a much improved chronostratigraphic data base are providing the basis for more rigorous tests of the concept of eustatic control of sequence stratigraphies at the 10^6-year scale. Global correlation can now be demonstrated for some Neogene sequences, but the correlations remain unconvincing for older strata. High-frequency orbital forcing of climate and possibly of sea–level is suggested by facies and oxygen isotope data for parts of the Cretaceous.

Introduction

The Vail-Haq-Hardenbol/Exxon "school" of sequence stratigraphy is continuing to develop sequence charts that purport to be global in scope and based on detailed chronostratigraphic analysis. Haq and Schutter (2008) offered a new "Chronology of Paleozoic sea-level changes" built following the same approach used by Vail et al. (1977), Haq et al. (1987) and Graciansky et al. (1998). Successions of sequences from selected "Reference Districts" were assembled into a single "global" chart. Each sequence boundary was assigned an absolute age to the nearest 0.1 m.y., but no assessments of potential error were provided for these ages. This chart contains 172 "discrete third-order events" averaging 1.7 m.y. per cycle. Current estimates of potential error in the geological time scale range between ±2 and 3 m.y., except for the Pennsylvanian and Permian, where the standard error drops to about ±1 m.y. (Hinnov and Ogg, 2007). The level of assumed accuracy and precision of this chart is therefore beyond what is technically possible. The problems with the Exxon "school" were detailed by Miall and Miall (2001).

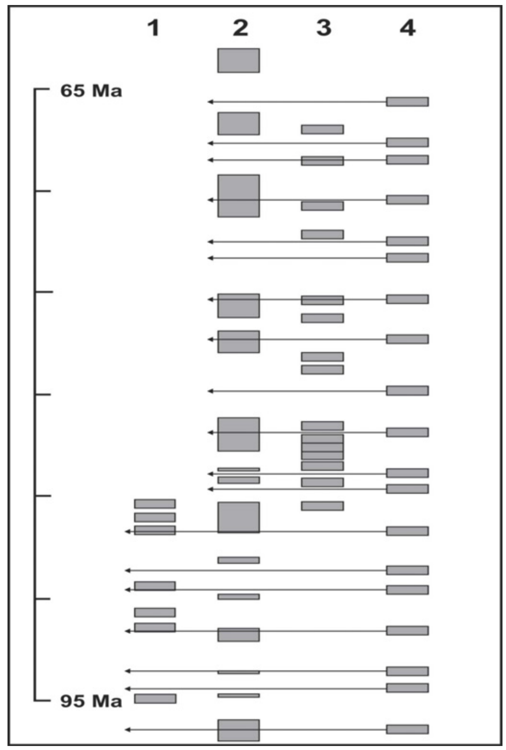

Figure 1. Comparison of the ages of sequence-bounding unconformities and other data relating to sea-level changes in four Upper Cretaceous data sets. The grey boxes indicate the interpreted durations of unconformities. **Column 1:** sea-level lowstands derived from the curves of Sahagian et al. (1996), whose data set deals with Santonian to Bajocian data and therefore ends at about 84 Ma. **Column 2.** Unconformities on the New Jersey continental shelf (Browning et al., 2008). **Column 3.** Sea-level lowstand events in the New Zealand stratigraphic record (Crampton et al., 2006). **Column 4.** Sea-level lowstands predicted from the model of Cretaceous glacioeustasy by Matthews and Frohlich (2002), as reproduced by Miller et al. (2005). The 2.4 m.y. long-eccentricity cycle is estimated to have been the dominant frequency.

An entirely different approach to the issue of sequence dating and correlation is being taken by K. G. Miller and his colleagues, who have focused on a detailed analysis of the Early Cretaceous-Pleistocene sequence architecture underlying the shallow subsurface of the New Jersey coastal plain and the immediately adjacent offshore. High-resolution seismic-reflection data provided the framework for the project, supplemented by methods of quantitative biostratigraphy, and oxygen- and strontium-isotope dating applied to core material. A leg of the Ocean Drilling Program that was actually drilled onshore (Leg 174AX), was devoted to this project, supplementing earlier legs (Leg 150, 150X) that were drilled on the New Jersey continental shelf (Miller et al., 1998; 2004, 2008; Browning et al., 2008). Backstripping analysis provided the basis for a local sea-level curve (Kominz et al., 2008).

Testing for eustasy in the Upper Cretaceous

Data from a single location, the New Jersey Atlantic margin, are insufficient to provide a test of global eustasy. To assess their relevance for global sequence patterns correlations must be performed into other, tectonically unrelated basins. Data sets for the Russian Platform (Sahagian et al., 1996) and New Zealand (2006) permit a global comparison with the New Jersey Upper Cretaceous sequence records. Because of faunal provincialism, global biostratigraphic correlations for the Upper Cretaceous are characterized by errors of ±2.5 m.y. Incorporation of all available chronostratigraphic data may reduce error to ±1 m.y. (Hinnov and Ogg, 2007), but in practice such precision is rarely obtainable.

The limited comparisons that can be made between the New Jersey, Russian and New Zealand data are shown in Figure 1. Column 4 indicates the position of sea-level lowstands predicted from a model of glacioeustasy proposed for the Cretaceous and early Cenozoic by Miller et al. (2005). The increasing evidence for the existence of continental ice during the so-called greenhouse climatic era of the Cretaceous is discussed later. At this point it can be noted that, despite the claims of Crampton et al. (2006) and Kominz et al. (2008), there is very little, if any, similarity between the ages of sea-level lowstands, as indicated in this chart. Only one of the predicted glacioeustatic lowstands, at about 76 Ma, is recorded both in the New Jersey and the New Zealand sections. One event occurs in both the New Jersey and Russian successions, at about 91.5 Ma (this is below the stratigraphic limit of the New Zealand data set). Modest revisions of assigned ages of sequence-bounding unconformities would bring several other events into line as contemporaneous events, and some events may be unrepresented because of incomplete sampling, unrecognized tectonic overprinting, or local autogenic causes. It could be argued that the margins of error associated with the global correlations between New Jersey, Russia and New Zealand would allow for adjustments of assigned sequence boundary ages by as much as 2 to 3 m.y., which would make a substantial difference to the picture that emerges from comparisons such as that shown in Fig. 1. However, this would be to return to the tail-wagging-dog circular reasoning of the Exxon school that should be avoided if the science is to make any real progress. As an examination of global eustasy, it must be concluded that the results of this synthesis, as it currently stands, are inconclusive.

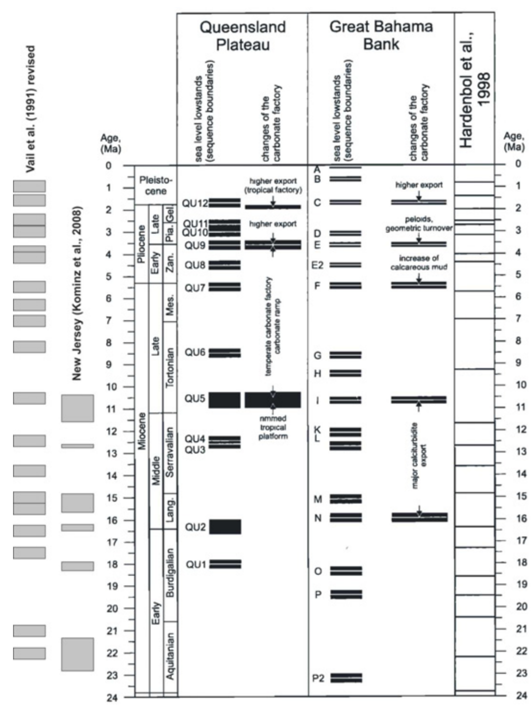

Figure 2. Comparison of Neogene sequence boundaries in the platform carbonate margins of Queensland and the Bahamas Bank. The sequence boundaries from the Hardenbol et al. (1998) scale are shown at right. From Betzler et al. (2000). Two additional sets of sequence boundaries have been added, at left, the sequence boundaries from the Miocene portion of the New Jersey record (from Kominz et al., 2008), and the Neogene record of the Antarctic (from Vail et al., 1991, with boundary ages revised by Hardenbol et al., 1998.

Testing for eustasy in the Neogene

Results derived from some Neogene data sets are more convincing, in terms of a possible global eustatic signal. Figure 2 is a modification of a correlation diagram developed by Betzler et al. (2000) comparing the Mio-Pliocene sequence record on the Bahamas Bank and the Queensland plateau, to which has been added the sequence boundaries from the same interval of the New Jersey continental margin succession (from Kominz et al., 2008). The Queensland-Bahamas study is based on correlations of calcareous nannoplankton and planktonic foraminifera. The density of the biostratigraphic data ranges from one to three biohorizons per million years. This diagram indicates a high degree of correlation between Queensland, New Jersey and the Bahamas during the Miocene.

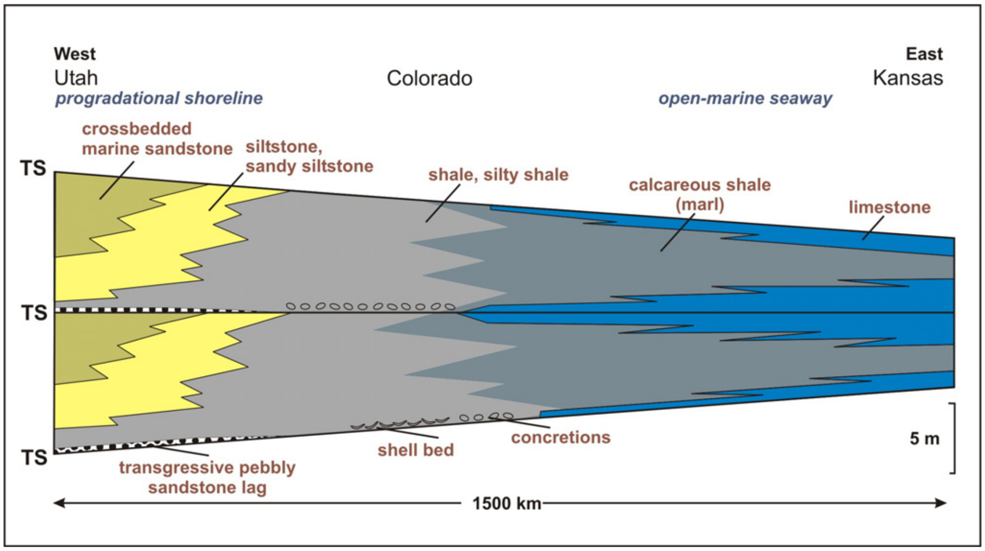

Fig. 3. Turonian sedimentation of the Rocky Mountain states. Correlation of clastic cycles along the basin margin, in Utah, with limestone-shale cycles of the Greenhorn formation in the basin centre (Colorado-Kansas). TS=transgressive surface. After Elder et al. (1994).

Milankovitch cyclicity and glacioeustasy in the Mesozoic and Early Cenozoic

There is growing evidence for glacioeustasy in the Mesozoic and early Cenozoic. Largely because of the large volume of oxygen isotope data acquired during ODP cruises over the last decade, the use of this class of data to evaluate late Cenozoic glacioeustasy and oceanic temperature changes has become so much part of standard methodology that the $\delta^{18}O$ curve is now accepted as an independent measure of geologic time. We are not at that point for the Mesozoic-early Cenozoic yet, but having said that, oxygen isotope data are now providing many essential new insights on climatic and oceanographic changes through that period. Several recent publications review this data set and argue the case for periodic development of small to moderate-sized ice-caps on the Antarctic continent through the so-called greenhouse period of the Mesozoic-early Cenozoic (e.g., Miller et al., 1999, 2005, 2008). Two detailed $\delta^{18}O$ studies focused on specific parts of the Cretaceous record. Miller et al. (1999) examined the Maastrichtian record in coastal sediments in New Jersey, and Borneman et al. (2008) discussed the implications of a $\delta^{18}O$ excursion during the Turonian.

Some stratigraphic studies of the Cretaceous record (e.g., Elder et al., 1994; Varban and Plint, 2008) have demonstrated the existence of a high-frequency stratigraphy that cross facies boundaries and shows no correlation to tectonic features (such as progressive forebulge onlap). In some cases, widespread facies changes may be related to orbitally-forced climate cycles. Figure 3 illustrates an example from the Rocky Mountain states. Cool-wet conditions favouring enhanced delivery of clastic detritus caused coarsening upward successions along the basin margin and a flood of mud into the basin centre, alternating with warm, dry phases which favoured reduced clastic sediment delivery and biogenic carbonate generation in the basin centre. Miller et al. (2005) argued the case for occasional “cold snaps” during the Cretaceous, leading to ice-cap development on Antarctica. This would provide a mechanism for glacioeustasy on a 10^{4-5}-year time scale.

Conclusions

Where detailed chronostratigraphic data permit accurate and precise global correlation, a stratigraphic signature of eustatic sea-level change with a 10^6-year periodicity, probably driven by Antarctic ice fluctuations, can be demonstrated for at least part of the Neogene record. Oxygen isotope fluctuations in the Cretaceous and early Cenozoic suggest periodic development of small to moderate-sized ice caps on Antarctica, but stratigraphic data are as yet inadequate to demonstrate convincing global correlations on the 10^6-year time scale. There is increasing stratigraphic evidence for the functioning of orbital forcing throughout the Phanerozoic, but accurate interbasin correlation for the pre-Neogene is not yet possible. Stratigraphic data are entirely inadequate to provide tests of global correlation at the 10^6-level for pre-Cretaceous stratigraphy, and so the development of any new "global cycle chart" is premature.

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